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Running Head: Don't sweat it.

Don't sweat it: Re-examining the Somatic Marker Hypothesis using variants of the Balloon
Analogue Risk Task

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Abstract

Current thinking on the role of emotions in decision making has been highly influenced by one theory – the Somatic Marker Hypothesis which emphasizes the role of physiological mechanisms in guiding decisions – and by variants of a single task – the Iowa Gambling Task (IGT) whose development is closely tied to that theory. To address potential shortcomings in the IGT, we use three variants of another task – the Balloon Analogue Risk Task – as a novel means of testing the SMH via behavioural and physiological arousal (skin conductance) data. We manipulated the emotional content of the task by altering its framing (loss vs. gain) and point of commitment to taking risk (in advance vs. in the moment), whilst also assessing skin conductance. We find consistent support for elements of the Somatic Marker Hypothesis: decisions ending in failure result in higher skin conductance than successes; and those failures inhibit risk taking on subsequent trials. However, we find little support for skin conductance guiding decision making – a core prediction of the SMH.

Keywords: sequential risk taking, Iowa gambling task, Balloon analogue risk task, skin conductance, emotion

INTRODUCTION

The Somatic Marker Hypothesis (SMH; Damasio, 1991; 1994; Bechara, Damasio, Damasio & Anderson, 1994) proposes that signals from the body, such as elevated heart rate and sweating, manifest themselves during decisions under uncertainty. These somatic states are activated by re-encountering a response option that had previously created the somatic state via punishment or reward, and act to warn the decision maker against previously encountered disadvantageous courses of action (Damasio, 1991). The SMH was developed to explain acquired deficits in decision making in patients with damage to the ventromedial prefrontal cortex (VMPFC); the proposed area for storage of these somatic markers (Damasio, Tranel & Damasio, 1991).

The Iowa Gambling Task (IGT; Bechara, et al., 1994) was the laboratory task devised to capture VMPFC lesion patients' real-life risk taking based on immediate gratification. Four decks of cards deliver a hypothetical \$-payoff when selected: two "good" decks return net outcomes of \$250 over 10 cards, and two "bad" decks deliver negative net outcomes of \$250 over 10 cards. The goal is to earn as much money as possible in 100 card selections: to be successful, participants must learn to forgo the immediate higher rewards of the bad decks in order to avoid the delayed higher punishments. According to the SMH, healthy participants learn to do this with experience by developing outcome somatic markers in response to high punishments in the bad decks. Over time, anticipatory markers develop *before* selecting (or considering selecting) from a bad deck, warning the player about the poor expected outcomes, causing a shift to selecting the good decks. VMPFC lesion patients, however, fail to convert the outcome somatic markers into anticipatory markers and continue to select the bad decks (Bechara, Tranel, Damasio & Damasio, 1996).

Support for the SMH rests on identifying these somatic markers, which have most commonly been assessed by measuring skin conductance responses (SCRs) before

(“anticipatory”) and after (“outcome”) each card selection. Bechara et al. (1996) found that healthy participants who perform well in the IGT showed elevated anticipatory SCRs when selecting from bad decks; whereas patients with VMPFC damage who performed poorly, did not. Many other studies have found support for healthy individuals developing anticipatory SCRs (e.g., Bechara, Damasio, Damasio & Lee, 1999; Bechara, Tranel & Damasio, 2000). Others have found variability in task performance and skin conductance among healthy controls. Bechara, Dolan, Denburg, Hindes, Anderson and Nathan (2001) found 13 out of 40 control participants performed no better than the highest performing VMPFC patient. Control participants with impaired IGT performance in Bechara and Damasio (2002) showed variability in their anticipatory SCRs, with some comparable to the VMPFC lesion patients. Suzuki, Hirota, Takasawa and Shigemasa (2003) divided participants by SCR magnitude, and found fewer selections from the bad decks for the high-SCR than the low-SCR group but only in later trials. Crone, Somsen, Van Beek and Van der Molen (2004) found that poor performers showed no such differences in their anticipatory SCRs for good and bad decks. Recently, Fernie and Tunney (2013) found a lack of differential anticipatory SCRs did not hinder successful play in the IGT.

The IGT has been criticized (see Dunn, Dalgleish & Lawrence, 2006 for review). Steingroever, Wetzels, Horstmann, Neumann and Wagenmakers (2013) question the standard interpretation of the IGT literature, noting that healthy participants often perform poorly, challenging the SMH, which predicts that healthy participants learn to choose well. This highlights that interpreting the data from the IGT in relation to the SMH is often not straightforward, and that the current state of affairs where a single task is the major source of data on the SMH is far from ideal.

In this paper, we apply the SMH to a sequential risk-taking task in which (as in the IGT) participants learn from experience. We test the SMH using the Balloon Analogue Risk

Task (BART; Lejuez et al., 2002) where participants inflate a virtual balloon and accrue money/points for each additional “pump” of the balloon, but lose these earnings if the balloon bursts before they decide to stop pumping and “bank” their earnings. We believe that physiological data during the BART has only been published by Hunt, Hopko, Bare, Lejuez and Robinson (2005) who found no relationship between the mean SC level (across an entire task) and risk taking. However, this ignores the trial-by-trial variation in physiological responses, as assessed in the IGT, and which the SMH predicts should occur. We therefore examine whether – in line with the SMH – physiological signals guide decisions in the BART.

STUDY 1

Using a standard BART with the addition of skin conductance (SC) measurement, we assess participants' physiological responses to successes (banking one's accrued points) and failures (not banking and therefore losing points when the balloon bursts) and whether these predict subsequent actions. We test three hypotheses derived from the SMH. First, as in the IGT where punishment cards elicit higher outcome SC than other cards, failures should elicit stronger physiological responses than successes. This first analysis is, in part, a manipulation check to ensure arousal is greater for a failure than a success. Therefore, we predict:

H₁: Outcome SC will be greater for failures (non-banks) than for successes (banks).

Greater physiological arousal in response to bad outcomes (H₁) should serve to warn against repeating poor courses of action, and greater arousal should guide behaviour more strongly (e.g., Carter & Smith Pasqualini, 2004); therefore, we predict:

H₂: The larger the outcome SC on the previous trial the lower the number of pumps on the current trial.

Finally, the SMH posits that not only do somatic signals mark outcomes and guide actions, but also that they do so by becoming associated with the anticipation of bad

outcomes when a course of action is being considered. In order to examine this anticipatory SC in the BART, we examine the final decision of each trial, in which the participants elects to bank or to pump again (which, on this occasion, results in a burst). The action (strategy) in the BART that is most likely to become “marked” is pumping when the balloon is more highly inflated, because this is the action most likely to be punished with the worst possible outcome (a burst); and so if anticipatory markers guide action they will do so by “warning” the decision maker against pumping too much. We therefore predict that:

H₃: Anticipatory SC will be greater before a bank than before a non-bank (i.e., a decision to keep pumping), and will therefore predict the final decision of a trial.

These three hypotheses are examined in Study 1, and again in two subsequent studies that alter the BART, to depress or enhance its “emotional character” in a manner designed to influence the formation and action of somatic markers.

Method

Participants. Forty-two participants (31 female) with a mean (standard deviation, SD) age of 20.45 (3.73) years and a range (inter-quartile range, IQR) of 18-36 (18-20) years took part. Four further participants were excluded due to either failing to follow instructions or apparatus error, and were replaced. For all studies, participants were recruited from the Psychology Department’s Volunteer list at the University of Essex (UK). Sample sizes were set, in advance, to be towards the upper range of that typical for physiological studies of decision making but a multiple of six to accommodate six counterbalanced block orders. No other conditions were included or dropped from analyses of this or Studies 2 and 3.

Apparatus and task. The SC activity was recorded using a Mind Media NeXus-10, using a sampling rate of 32 samples per second. SC activity was recorded continuously, and a trigger marked the SC reading at the end of every trial (when the balloon burst or the participant banked). The SC data were analysed using Ledalab, (Benedek & Kaernbach,

2010) using continuous decomposition analysis (fitting to each participant individually) with no down-sampling of the data. Data were analysed using Stata in all three studies.

On each trial of the BART, participants pumped a balloon by clicking the “Press to Pump” button using the computer’s mouse, collecting 1 point for every pump. Each pump increased the balloon by 3 pixels in height and width. The points accrued (so far) on the current trial, and the points earned on the previous trial were also displayed. To bank their points, participants clicked the “Press to Collect” button. Sound effects accompanied the end of each trial: either a “coin rattle” or a “balloon pop”, as appropriate. There were 30 trials.

Each trial had a predetermined burst point and if the number of pumps reached that number, the balloon “popped” and any points accumulated were lost. The burst points were drawn at random from a uniform [1,128] distribution, with the 10th burst point in each 10-trial block fixed to ensure a mean burst point of 64 in the block. This procedure matched previous instantiations of the BART (e.g., Lejuez et al., 2002), and ensures that each block can provide a similar quality of feedback on the task structure (Walasek, Wright & Rakow, 2014). The presentation order of the three blocks was counterbalanced across participants (six different orders). The order of the burst points was fixed within each block (i.e., not randomized).

Procedure. Participants completed the BART after another risk taking task (not reported here). The study lasted approximately 30 minutes; participants received a performance-contingent payment of UK£0.50 for every 500 points, plus a show-up fee of £5 (or course credit). The (gelled) sensors were attached to the distal phalange of the first and third digits of the participant’s non-dominant hand and their hand was placed palm upwards and asked to keep it as still as possible. As recommended, the sensors were given 5 minutes to settle and a baseline measurement was taken (Figner & Murphy, 2011). There was no time constraint on how quickly participants could pump but the inter-trial interval (i.e., between balloons) was set to 8 seconds.

Measures and data analyses techniques. The measure of SC was the mean phasic driver within the response window¹: in the interval from 1 to 4 seconds after the trial outcome (bank or burst) for outcome SC; and within the 2 seconds prior to the trial outcome for the anticipatory SC. All trials were analysed (i.e., *not* only those that end in a bank, as is often the case). We analysed the number of pumps on each trial and how each trial ended (bank or non-bank). Due to the repeated-measures design, all regressions (here and in Studies 2 and 3) were run using a multilevel random intercepts regression model fit using maximum likelihood estimation (Nezlek, Schröder-Abe, & Schütz, 2006). This technique allows us to examine trial-by-trial data in a principled fashion (e.g., by not treating trials as if they were independent observations) and this regression approach is, we argue, particularly useful for testing the *causal* role of somatic markers that the SMH posits because SC can be used as a *predictor* variable (alongside other predictors, if desired)².

Research has shown both inter- and intra-individual variability in the rise and recovery time of SCRs (Breault & Ducharme, 1993; Edelberg & Muller, 1981); which we accounted for by entering participant as a random intercept at level 2 within the multilevel model, and included random slopes for SC (when used as a predictor). Individual repeated judgments entered at level 1 (29-30 data points in this study) included participants' scores on the BART (number of pumps on the current trial; the previous trial outcome) and SC measures (previous trial outcome SC). The dependent variable was either the outcome SC (H₁), or the number of pumps per trial (H₂) or the final decision of a trial (H₃). We checked

¹ Ledalab documentation states this variable “represents phasic activity within the response window most accurately, but does not fall back on classic SCR amplitudes” (Benedek & Kaernbach, 2010).

² Conversely, the standard analysis of anticipatory SC in the IGT treats SC as a dependent variable in an ANOVA model, and the deck selection that follows as an independent variable. This makes it hard to rule out epiphenomenal accounts of SCRs, whereby, for example, previous outcomes predict outcome SC and also predict future decisions, but outcome SC plays no causal role in future decisions. In contrast, multilevel modeling allows us control for previous outcome when testing the (predictive) effect of outcome SC on future behaviour.

for skew in the continuous dependent variables for each participant individually for each regression. Outcome SC was positively skewed, so was \log_{10} transformed for all participants. Any marginal means reported for the skew-corrected data are the log-transformed scores. We identified multivariate outliers in our set of predictor variables, and removed those outliers from all regression analyses (Billor, Hadi & Velleman, 1999). No other measures were collected but not reported here, or in Studies 2 and 3.

Results and Discussion

Table 1 summarises the distribution of each dependent variable.

Table 1. Study 1: Mean, standard deviation (SD), minimum and maximum scores for non-skew corrected variables.

	Number of pumps per trial	Adjusted number of pumps	Total number of bursts (/30)	Outcome SC (μ Siemens/sec)
Mean	27.65	29.36	5.36	0.95
SD	15.47	15.77	3.50	0.98
Minimum	0	0	0	0
Maximum	91	115	19	4.64

Summary measures are across trials except for number of bursts (/30), which is across participants. Outcome SC scores summarized here are not corrected for skew, but were corrected for skew when analysed as a dependent variable via regression.

Multilevel analyses for H_1 . First, we regressed outcome SC on participant as a level 2 variable (Model 1) and then outcome SC on trial outcome (Model 2), see *Table S1 in online supplementary materials*. Model 1 revealed significant between-participant variation about the grand mean, with 51% of the error variance associated with participant (intra-cluster correlation, ICC). Model 2 showed that participants' outcome SC was significantly and substantially greater after a non-bank than a bank, $b = -.45$, $z = -18.24$, $p < .001$, supporting H_1 .

Multilevel analyses for H_2 . We initially regressed pumps per trial on participant as a level 2 variable (Model 1) and then regressed pumps per trial on previous trial outcome (Model 2) to control for the effect of the trial outcome (see *Table S2 in online supplementary*

materials). The coefficient of the grand mean intercept in Model 1 corresponded to an average of 27.70 pumps per trial, reflecting risk aversion (64 pumps per trial maximizes expected value); 19% of the error variance in the random part of the model was associated with participant. Model 2 shows that participants pumped more when the previous trial had ended in a bank, $b = 5.11$, $z = 5.85$, $p < .001$, with approximately five more pumps following a bank than following a non-bank. This was expected, because BART participants typically pump more following a bank than a burst (e.g., Wallsten, Pleskac & Lejuez, 2005).

To examine the influence of SC on pumping (H_2), previous SC outcome (variable centered) was added as a predictor (Model 3). Higher outcome SC resulted in fewer pumps on the next trial, $b = -1.48$, $z = -2.96$, $p = .003$. Thus, *over and above* the effect of how the previous trial ended, when participants experience high SC they tend to pump less on the next trial, supporting H_2 . The interaction between previous trial outcome and previous outcome SC was entered (Model 4; continuous variable centered) but was not significant, $z < 1$; this addition did not significantly improve the model ($p = .848$).

Multilevel analyses for H_3 . We regressed the final decision of each trial (non-bank = 0, bank = 1) on participant as a level 2 variable (Model 1), which confirmed that there was significant variation between participants (see *Table S3 in online supplementary materials*). Adding anticipatory SC as a predictor (variable centered; Model 2) we found that (supporting H_3) for every unit (μ Siemens/sec) increase in anticipatory SC, the odds of the trial ending in a decision to bank increased by 1.39, $z = 2.85$, $p = .004$.³ To control for the length of the trial, we entered number of pumps (variable centered) to the next model, and found that for every additional pump the odds of the trial ending in a decision to bank increased by 1.04, $z = 6.85$, $p < .001$; while anticipatory SC remained a significant predictor, Odds = 1.40, $z = 2.69$, p

³ Here we examine the effect of anticipatory prior to controlling for the trial outcome; but we have also examined H_3 by entering the final decision of the trial in Model 2 and anticipatory SC in Model 3 (i.e., first controlling for trial outcome). In all three studies, reversing the order in this way did not affect which effects were found.

= .007, further supporting H_3 . The interaction term (variables centered) entered in the next model was not significant, $z < 1$.

The results from Study 1 suggest that participants differentiate the outcomes on the BART – marking failures (non-banks) with greater SC than successes (banks). This mirrors findings in the IGT and is consistent with the SMH. Both the actual outcome of the previous trial and the SC associated with that outcome, independently predicted participants' behavior on the next trial. Bursting the balloon led to an average of five fewer pumps on the subsequent trial, and having higher SC decreased the number of pumps by approximately one pump per $\mu\text{Siemen/second}$. Also, the greater the anticipatory SC, the greater the chance of the trial ending with a decision to bank.

In two subsequent studies, we further investigate the role of SC in the BART as a means of testing the SMH, by altering features of the BART that are pertinent to the role of emotions in decision making. In Study 2, we devised an “Offline” version of the task, where the number of pumps for each balloon was stated upfront (which should dampen emotional reactions). In Study 3, we devised a loss-framed BART where pumping served to avoid loss (which should heighten emotional reactions).

STUDY 2

We compare an “Offline” BART, in which participants decide how many times to pump at the start of each trial, with the standard (“Online”) BART in which decisions can be made “on the fly” and “in the moment”. A similar distinction exists between the “Hot” and “Cold” Columbia Card Tasks (CCT; Figner, Mackinlay, Wilkening & Weber, 2009) where the number of cards to be turned over is either stated upfront with no immediate feedback, or participants make stepwise incremental decisions and elect when to stop picking. The Offline BART could be considered a less arousing version of the BART: the decision about how much to pump is an “advance directive” that cannot be altered in response to subsequent

changes in targets or confidence, and so outcomes (good or bad) are not the result of a decision made just a moment ago.

A version of the BART similar to our Offline BART – the Automatic BART – was successfully used by Pleskac, Wallsten, Wang and Lejuez (2008) to capture the target number of pumps that a participant *wished* to make; to avoid discarding trials when computing the standard measure of risk taking in the BART (the mean adjusted number of pumps). Pleskac et al. (2008) found that the target scores in the Automatic BART closely matched the pumping found in the standard BART. Our rationale for using the Offline (Automatic) BART differs from that of Pleskac et al. (2008): we manipulate the emotional character of the BART to examine the role of emotions (indexed by SC) in sequential risk taking – thereby subjecting the SMH to further scrutiny. We conjecture that the Offline BART will be less arousing than the original BART, and that, therefore, the role of emotions may be diminished. Conversely, however, the Offline BART brings the period of deliberation closer to the time of the previous trial outcome and its associated outcome SC, and so it is possible that trial outcome and outcome SC will predict behavior in the next trial more strongly than in the (standard) Online BART. However, whatever the differences in the emotional/deliberative character of the Online and Offline versions, SC in the final seconds of a trial in the Offline BART (i.e., the “anticipatory” SC) can no longer guide or impact the decision to stop pumping.

We test the same three hypotheses set out in Study 1 but expect more pronounced emotional reactions in the Online BART compared to the Offline. We predict higher SC in response to failures in the Online BART, reflecting both the disappointment of a bad outcome *and* the regret associated with a very recent decision. In contrast, while one may still regret one's decision in the Offline BART, the relevant decision is more distant and less likely to

elicit extreme reactions, again acting as a manipulation check on the levels of arousal elicited.

Thus, we examine a modification of H_1 :

H_{1a} : Outcome SC will be greater for failures (non-banks) than for successes (banks), and more so in the Online BART.

We will also examine whether task version moderates the effects predicted in H_2 (greater previous outcome SC leading to fewer pumps on the next trial). However, we have competing predictions (discussed above): the deliberative character of the Offline BART may reduce this effect, or bringing the decision about how much risk to take closer to the previous outcome in the Offline BART may amplify the effect.

Given anticipatory SC in the final moments of the trial cannot alter the decision that was made some seconds earlier in the Offline BART, we have a clear prediction that the task version will moderate the effect:

H_{3a} : Anticipatory SC will be greater before a bank than before a non-bank, and will therefore predict the final decision of a trial in the Online BART, but not in the Offline BART.

Method

Participants. There were 36 participants (23 female) with a mean (SD) age of 24.33 (3.80) years and a range (IQR) of 19-35 (22-26) years. Two further participants were excluded due to not following instructions correctly or apparatus error, and were replaced.

Apparatus and task. The version of the BART from Study 1 was used with some modifications. Participants had to click a button labelled “Click to start pumping” at the start of each trial just above the “Press to pump” button. To avoid very early bursts (arguably implausible for the balloon cover story) the burst points were set to occur between 15 to 128 pumps, but still with a mean burst point of 64 in each block, and sound effects were removed. To increase participants’ awareness of the instructions, participants were instructed to click on the balloon displayed on the screen instead of the “next” button in order to move between

screens of instructions (Oppenheimer, Meyvis & Davidenko, 2009). Lastly, participants were shown screen shots of a balloon pumped to 25%, and 75% of the total size to help orientate participants to the task (Pleskac et al., 2008). The Offline BART differed only by requiring participants to enter the number of pumps they wished to make on each balloon (in advance) before they started pumping. If the specified number of pumps was reached without the balloon bursting, a message appeared telling them to collect their points. This ensured that all behavioural and physiological measures were taken at equivalent points of the two versions.

Design. Participants completed both versions of the BART in a within-subjects design (with the order of versions counterbalanced, and >5 minutes between tasks). The order of the pre-set burst points was randomized within blocks, and block order was counterbalanced via a Latin square with the additional constraint that participants did not encounter the same initial block in both versions.

Procedure. The session took approximately 50 minutes; participants were paid £5 plus £0.50 for every 500 points (for both BARTs). The study setup and the measures taken were identical to Study 1, except that (as recommended; Figner & Murphy, 2011) participants completed a questionnaire filler task during the initial SC baseline-recording period.

Results and Discussion

Table 2 shows the distribution of each dependent variable, for both task versions.

Table 2. Study 2: Mean, standard deviation (SD), minimum and maximum scores for each version of the BART.

	Number of pumps per trial		Adjusted pumps per trial		Total number of bursts (/30)		Outcome SC (μ Siemens/sec)	
	Online	Offline	Online	Offline	Online	Offline	Online	Offline
Mean	33.87	32.12	35.02	32.69	5.30	4.81	0.72	0.47
SD	15.07	14.52	15.03	15.71	3.48	3.43	0.92	0.68
Minimum	4	2	4	2	0	0	0	0
Maximum	105	100	105	100	18	17	4.59	4.03

Summary measures are across trials except for number of bursts (/30), which is across participants. Outcome SC scores summarized here are not corrected for skew, but were corrected for skew when analysed as a dependent variable via regression.

Multilevel analyses for H_{1a}. To examine variability in outcome SC, we first regressed outcome SC on participant as a level 2 variable (see *Table S4 in online supplementary materials*). This revealed that 28% of the error variance was associated with participant – again supporting the use of multilevel models to analyse these data. In Model 2, we regressed outcome SC on version (Online = 0, Offline = 1), order (Online first = 0, Offline first = 1), and their interaction. There was a main effect of version, with greater outcome SC in the Online than the Offline BART, $b = -.19$, $z = -5.37$, $p < .001$. There was no significant effect of order, or its interaction with version; therefore, order was dropped from subsequent models while version was retained. To test H_{1a}, in Model 3, we added (previous) trial outcome (burst = 0, bank = 1) and the interaction with version as predictors. As in Study 1, outcome SC was substantially greater after a non-bank than a bank, $b = -.50$, $z = -13.86$, $p < .001$, and more so in the Online BART, $b = .15$, $z = 2.96$, $p = .003$, supporting H_{1a}.

Multilevel analyses for H₂. We first regressed pumps per trial on participant as a level 2 variable (see *Table S5 in online supplementary materials*). The coefficient of the grand mean intercept corresponded to 33.2 pumps on average – again indicating risk aversion, though less so than in Study 1. We then regressed pumps per trial on version, order (predictors coded as above) and their interaction term (Model 2). Only the interaction between version and order was significant $b = -4.88$, $z = -3.97$, $p < .001$. This effect in itself is not critical to our consideration of the SMH, but was included in all subsequent models together with version to allow full consideration of our design when exploring whether version was a moderator.

We regressed the number of pumps per trial on previous trial outcome (non-bank = 0, bank = 1) and the interaction between previous trial outcome and version (Model 3). As found in Study 1, participants pumped more when the previous trial had ended in a bank, $b =$

3.20, $z = 3.39$, $p = .001$. Additionally, the interaction between previous trial outcome and version was significant, $b = -3.61$, $z = -2.72$, $p = .007$: matching what was found in Study 1 participants pumped fewer times following a non-bank (Offline $M_{\text{Marginal}} = 30.21$; Online $M_{\text{Marginal}} = 31.86$) than a bank (Offline $M_{\text{Marginal}} = 33.40$; Online $M_{\text{Marginal}} = 35.06$).

To examine the influence of outcome SC on subsequent pumping (H_2), previous outcome SC and its interaction with version (continuous variables centered) were added as predictors (Model 4), which resulted in a marginal improvement of the overall model fit (vs. Model 3, $p = .054$). Previous outcome SC was a marginally significant predictor, $b = -1.26$, $z = -1.94$, $p = .052$, with higher SC predicting fewer pumps on the next trial; however, the interaction between previous outcome SC and version was significant, $b = 1.68$, $z = 2.13$, $p = .033$, with higher previous outcome SC predicting a *greater* number of pumps on the next trial in the Offline version (i.e., opposite to the direction predicted in H_2) but not in the Online version. The significant interaction between previous trial outcome and version in Model 3 also became non-significant in Model 4; however the main effect of previous trial outcome remained, with more pumps on the next trial following a bank.

Multilevel analyses for H_{3a} . We regressed the final decision of each trial (non-bank = 0, bank = 1) on participant as a level 2 variable (Model 1). We then entered anticipatory SC (centered; Model 2), however, unlike Study 1, it was *not* a significant predictor, $z < 1$ (see *Table S6 in online supplementary materials*). To check for effects of version and their order (Model 3), we regressed the final decision of the trial on version, the order of the versions, and their interaction, together with anticipatory SC and its interaction with version (H_{3a}). None of these effects were significant (all p 's $> .283$); therefore we find no support for H_{3a} . We then included number of pumps (variable centered) retaining version, anticipatory SC and their interaction (Model 4). We found that for each additional pump, the odds of the trial

ending in a decision to bank increased by 1.03, $z = 7.73$, $p < .001$, and all other effects remained non-significant, (z 's < 1.68 , p 's $> .093$).

STUDY 3

The SMH predicts, and studies involving the IGT have shown, greater physiological responses to losses than to gains. This finding has been observed in a variety of tasks (Hochman & Yechiam, 2011; Satterthwaite et al., 2007); and fits with the general observation, often reported, that negative events impact us more than positive events (Baumeister, Bratslavsky, Finkenauer & Vohs, 2001; Kahneman & Tversky, 1979). The BART has previously been modified to examine the effects of framing that are predicted by prospect theory (Kahneman & Tversky, 1979). Consistent with the payoff domain effect (reflection effect) documented by Kahneman and Tversky (1979) and instantiated in their prospect theory value function, Benjamin and Robbins (2007) found a loss-framed BART produced more risk seeking behaviour.

In Study 3 we tested the impact of framing on SC and risk taking. It is not clear whether this effect alone should lead us to expect a differential effect of frame on the effects set out in hypotheses H₁ to H₃. However, as discussed above, we anticipate greater emotional reactions to, and greater impact from, failures framed as losses than to those framed as foregone gains, and therefore predict:

H_{1b}: Outcome SC will be greater for failures (non-banks) than for successes (banks), and more so in the loss frame.

Consistent with clearer somatic marking guiding action more strongly (Carter & Smith Pasqualini, 2004), we predict that this effect of frame on the intensity of emotional response will moderate the effect of outcome SC on subsequent risk taking:

H_{2b}: The larger the outcome SC on the previous trial the lower the number of pumps on the current trial, and more so in the loss frame.

Likewise, when events are marked more clearly by somatic states, somatic markers should arise more readily when the potential for those events to occur is considered at a subsequent point in the task. We therefore predict that:

H_{3b}: Anticipatory SC will be greater before a bank than before a non-bank, and will therefore predict the final decision of a trial, and more so in a loss frame.

Method

Participants. There were 36 participants (25 female) with a mean (SD) age of 22.03 (5.88) years and a range (IQR) of 18-44 (19-23) years. Two further participants were excluded for not following instructions and were replaced.

Apparatus and task. The Online BART used in Study 2 was used create the new loss-frame and gain-frame BARTs. In the Gain BART, labels were changed to “Pumps So Far” and “Money Gained So Far” (which showed an increase of 1 pence with each pump). At the end of the trial, a label showing the “Money Gained on Balloon” was displayed, which showed “0 pence” if the balloon had burst. The equivalent adaptations were made to create the Loss BART, but changed to “Money Lost So Far” (which started at 128 pence and reduced by 1 pence with each pump). At the end of the trial, the “Money Lost on Balloon” label was displayed. If the balloon had burst, the label showed that 128 pence had been lost.

Design. Participants completed both versions (frames) of the BART in a within-subjects design with frame order counterbalanced. The burst points were randomized within each block, and the order of the blocks was fully counterbalanced.

Procedure. The study lasted approximately 50 minutes. Participants were paid £5 and a performance-contingent payment (from one trial of each version of the BART). The procedure was the same as Study 2, except for the required changes to the task instructions (below) and screen layout (above), and a small reduction in the inter-trial interval to 6 seconds. The additional instructions in either a loss or gain frame were modified from

Benjamin and Robbins (2007). Once the 3-minute baseline period was over, the experimenter checked the participants' understanding of the tasks. In the Loss BART, participants were shown 128 pence (in coins) and told it was their money (i.e., starting balance). They were then asked three questions about how much they would *lose* from their balance if they pumped a specified number of times. In the Gain BART participants were shown 128 pence and told they could win up to this amount and were asked the same three questions but regarding how much they would *gain*. In both versions of the BART one balloon would be selected and the amount retained from the endowed 128 pence in the Loss BART and the amount gained out of the potential 128 pence in the Gain BART would be added together as payment; if the balloon burst on the trial selected this resulted in no payment. Participants completed an unrelated filler task between the two BART versions, ensuring at least 10 minutes between the two BARTs.

Results and Discussion

The distributions for the dependent variables are summarized in *Table 3*, for each version (frame) of the BART.

Table 3. Study 3: Means, standard deviation (SD), minimum and maximum scores for each frame of the BART.

	Number of pumps per trial		Adjusted pumps per trial		Total number of bursts (/30)		Outcome SC (μSiemens/sec)	
	Gain	Loss	Gain	Loss	Gain	Loss	Gain	Loss
Mean	41.68	43.69	46.00	49.12	7.33	7.59	0.71	0.78
SD	20.96	22.50	22.49	24.12	4.81	4.60	0.91	0.87
Minimum	5	1	5	1	0	0	0	0
Maximum	120	128	120	120	23	22	5.49	5.56

Summary measures are across trials except for number of bursts (/30), which is across participants. Outcome SC scores summarized here are not corrected for skew, but were corrected for skew when analysed as a dependent variable via regression.

Multilevel analyses for H_{1b} . We regressed SC outcome on participant as a level 2 variable (see *Table S7 in online supplementary materials*). This initial model revealed that

60% of the error variance was associated with participant – again confirming multilevel modeling as appropriate. We then regressed outcome SC on frame (Loss BART = 0, Gain BART = 1), frame order (Loss BART first = 0, Gain BART first = 1), and their interaction term (Model 2). There was no main effect of frame, order effect or interaction. Consequently, only frame was retained as a predictor to test H_{1b} . We regressed outcome SC on trial outcome and its interaction with frame (Model 3). We again found the predicted main effect of trial outcome, $b = -.16$, $z = -5.24$, $p < .001$; though the interaction between frame and trial outcome was not significant, $b = .054$, $z = 1.33$, $p = .184$. Thus, it is true that outcome SC was greater after non-banks (Gain BART $M_{\text{Marginal}} = -0.39$, Loss BART $M_{\text{Marginal}} = -0.32$) than after banks (Gain BART $M_{\text{Marginal}} = -0.54$, Loss BART $M_{\text{Marginal}} = -0.48$) supporting H_1 , and, while the marginal means were in the right direction, H_{1b} was not supported.

Multilevel analyses for H_{2b} . We first regressed the number of pumps per trial on participant as a level 2 variable, and found significant between-subjects variability (see *Table S8 in online supplementary materials*). The coefficient of the grand mean intercept, corresponded to an average of 42.99 pumps per trial; again indicative of risk aversion, but with greater risk taking than in Studies 1 or 2. This may reflect that, unlike Studies 1 and 2, participants in Study 3 could infer the maximum number of pumps; thus the typical tendency towards risk aversion is not further compounded by uncertainty about the properties of the task (see Pleskac, 2008, for sequential risk taking in ill-defined and defined environments). We then regressed pumps per trial on frame (loss or gain), frame order, and their interaction term (Model 2). Only frame was significant, with more pumps per trial in the Loss BART than the Gain BART, $b = -3.36$, $z = -2.59$, $p = .010$ (and so frame was retained in all subsequent models) showing greater risk seeking in the loss frame than in the gain frame. We added previous trial outcome and its interaction with frame as predictors (Model 3). As found previously, participants pumped more when the previous trial had ended in a bank, $b = 3.61$, z

$= 2.76, p = .006$; however, there was no interaction with frame. Thus, for the standard BART (as in Studies 1 and 2), participants pumped less after a non-bank than a bank – however, the framing did not alter this reaction to the previous outcome.

To examine the influence of outcome SC on subsequent risk taking (H_{2b}), previous outcome SC and its interaction (continuous variables centered) with frame were added in Model 4. There was no main effect of previous outcome SC, though the interaction between previous outcome SC and frame was significant, $b = -1.86, z = -2.05, p = .040$. Thus, higher outcome SC on the previous trial was associated with increased risk taking in the loss frame but with decreased risk taking in the gain frame (holding the other predictors constant). Thus, H_2 was supported in the Gain BART; while the opposite direction of effect was found in the loss BART with *higher* previous SC leading to *greater* pumping on the next trial.

Multilevel analyses for H_{3b} . We first regressed the final decision of each trial (non-bank = 0, bank = 1) on participant as a level 2 variable (again finding this model a significant improvement upon standard logistic regression). In Model 2, we found no effect of anticipatory SC when it was added as an additional predictor (centered), $z < 1$ (see *Table S9 in online supplementary materials*). In Model 3 we tested for effects of frame and frame order and their interaction, together with anticipatory SC and its interaction with frame, but all predictors were non-significant (all p 's $> .292$); thus there was also no support for H_{3b} . We then added number of pumps (variable centered) while retaining frame, anticipatory SC and their interaction (Model 4). Consistent with Studies 1 and 2 we found that for each additional pump the odds of the trial ending in a bank increased by 1.04, $z = 14.10, p < .001$. The effect of frame was now significant, Odds Ratio = 1.30, $z = 2.24, p = .025$; indicating a greater chance of banking at a given stage of the trial in the gain frame.

Re-analysis according to what strategy is optimal. At the suggestion of a reviewer, we examined whether the predictors of the outcome SC (H_{1b}) and the decision to stop pumping

(H3_b) differed according to whether participants *should* be pumping more, or less, by analysing trials ending at ≤ 64 pumps separately from trials ending at ≥ 65 pumps (64 pumps per trial maximizes expected value). (Such analysis was not feasible for Studies 1 and 2 because participants rarely pumped more than 64 times). These analyses yielded the same pattern of significant effects in respect of H1_b (see *Tables S7a and S7b in the online supplementary materials*), except that for “long” trials frame was no longer a significant predictor in the final model. With respect to H3_b, the analysis of “short” trials yielded the same findings as the original analysis (see *Table S9a in online supplementary materials*). For “long” trials, anticipatory SC was significantly greater prior to a decision to bank (Model 2), suggesting anticipatory SC plays a role later on in a trial (when the balloon is more likely to burst); though this effect was no longer significant when pumps per trial was also a predictor (Model 3, see *Table S9b in online supplementary materials*).

GENERAL DISCUSSION

In three studies, we examined whether the Somatic Marker Hypothesis (SMH; Damasio, 1991; 1994) could explain behaviour in variants of the Balloon Analogue Risk Task (BART). Previous tests of the SMH have focused almost exclusively on variants of the Iowa Gambling Task (IGT); we therefore derived three hypotheses from the SMH that allowed us to undertake much-needed tests of this prominent theory of the role of emotions in decision making.

We consistently found (in all three studies) that trials ending in failure (a burst) where the participant had decided to continue pumping, prompted greater skin conductance (SC) than trials that ended in a decision to cease pumping (banking points). This result is in keeping with findings from the IGT, in which losses/failures elicit higher SC than gains (e.g., Suzuki et al., 2003); is consistent with the SMH insofar as somatic reactions to outcomes are necessary (though not sufficient) for the subsequent formation of anticipatory somatic

markers; and provides a manipulation check on our physiological data (because a burst is a surprising outcome). The emotional character of the task can moderate this effect of outcome on SC. Our Offline BART (Study 2), in which successes and failures resulted from decisions made well in advance of their precipitating actions, elicited lower SC in response to those outcomes. Additionally, the difference in outcome SC between successes and failures was lower in this more “emotionally detached” version of the BART than in a standard Online version. This is in line with differences in SC between the “Hot” and “Cold” Columbia Card Tasks (Figner et al., 2009). The Cold task, in which (like our Offline BART) participants specify “advance directives”, elicited lower SC than the Hot task. Our loss-framed BART (Study 3) increased the level of SC on trial outcomes compared to a gain-frame. However, this did not significantly moderate the effect of outcome.

Support for the second hypothesis (that lower risk taking would follow a higher outcome SC) was inconsistent; with significant support for this prediction (which was derived from the SMH) in Study 1 and in the Online (Study 2) and Gain (Study 3) versions of the BART. This pattern was confirmed in a combined analysis of H_2 across all three studies with condition dummy coded: the (overall) main effect of outcome SC was negative as predicted but significantly reversed in the Offline BART and the Loss BART. A reviewer suggested that healthy participants might rely on somatic markers from several previous trials rather than only the most recent one, as has been shown to occur in the IGT (Yechiam, Busemeyer, Stout & Bechara, 2005). However, analyses for H_2 using the average previous SC did not provide a clearer picture for outcome SC predicting pumping on the subsequent trials. The only significant effect of average previous SC was found in Study 3 where higher average outcome SC on previous trials was associated with increased risk taking, whilst controlling for average previous trial outcomes and frame.

Our third hypothesis tested the contentious proposition (see Dunn et al., 2006) that somatic markers arise when the decision maker considers a poor course of action, and serve to warn the decision maker away from that action. As the worst possible outcomes in the BART arise when one pumps too much, we predicted, based on the SMH, elevated SC just before the decision to stop pumping and to bank. This was found to be the case in Study 1, where, as hypothesized, the anticipatory SC predicted whether the participant banked or continued to pump. However, this finding was not replicated in any of the versions of the BART examined in Studies 2 and 3.

To check whether our lack of consistent SC effects could be attributed to limited power in any one study, we analysed H_3 for all three studies together while dummy coding for condition. This showed that the effect predicted in H_3 was significantly larger in Study 1 than in all other studies. Moreover, no overall effect of anticipatory SC was detected across Studies 2 and 3 (combined) – which, according to the SMH, should occur for three of the four conditions run (Offline BART excepted). It is difficult to know why H_3 was corroborated in Study 1, but not consistently elsewhere – but our data suggest that finding an effect of anticipatory SC is the exception rather than the norm.

However, looking at decisions to bank made early (prior to reaching 65 pumps) and late (made after reaching 64 pumps) in Study 3, anticipatory SC was greater on trials where participants chose to bank, compared to trials that ended in a burst for decisions made later on. This result suggests that it is not until later on in a trial, when the balloon is at much greater risk of bursting, that participants might be making use of their physiological reactions. It is also difficult to ascertain what level of knowledge our participants had regarding the best course of action in the BART. Conscious knowledge in the IGT has been assessed on a number of occasions (Bechara et al., 1997; Maia & McClelland, 2004) and been shown to vary across healthy controls; with successful players more likely to show the typical SC

pattern expected by the SMH compared to absent or irregular SC results for the poorer players. As optimal play is rare in the BART, assessing participants' knowledge of the game might provide insights into their strategies and whether non-conscious strategies are needed.

The BART elicits emotional reactions to the outcomes reported in other risk-taking tasks such as the IGT (Bechara, et al., 1994) and the Columbia Card Task (Figner et al., 2009); these are readily detected via SC measurement; and can be successfully analysed on a trial-by-trial basis using multilevel models. The BART is therefore a suitable task for (further) investigating the physiological components of decision making. However, the predictions we derived from the SMH were corroborated by the data approximately 50% of the time, and H_3 , which spoke most directly to the unique elements of the SMH, was only consistently supported in Study 1. Specifically, in a sequence of decisions, the previous outcome predicts the amount of risk that the decision maker takes on their next decision and those outcomes are marked by somatic signals (H_1); but the presence or size of those signals does not consistently predict what the decision maker does next (H_2 and H_3). Thus, we find clear evidence of physiological arousal in decisions under uncertainty, but we find little evidence that this guides decisions in the manner predicted by the SMH.

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